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FOR: SIGNAL CONVERTER FOR CONVERTING DIGITAL INPUT SIGNAL TO OPTICAL MODULATION SIGNAL

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SIGNAL CONVERTER FOR CONVERTING DIGITAL INPUT SIGNAL TO OPTICAL MODULATION SIGNAL

The present application is based on Japanese patent application No.2003-163661, the entire contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

The present invention relates to a signal converter for converting digital input signals to optical modulation signals to output the converted signals, and particularly to a signal converter wherein amplitude control and bias control are simplified.

DESCRIPTION OF THE RELATED ART

A well-known optical modulator (for example, an LN modulator) is used as a means for optical modulation in a signal converter in which electrical digital signals are converted to optical modulation signals. This type of an optical modulator applies intensity modulation to continuous light having constant intensity. There are a signal electric power proportional to digital input signals and a bias electric power composed of direct current, as an electric power for intensity modulation to be applied to the continuous light. Such signal electric power and bias electric power must be appropriate

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values for optical modulation signals to be linear with respect to digital input signals without signal distortion.

FIG. 1 shows a conventional signal converter including a circuit for obtaining suitable values of signal electric power and bias electric power, respectively. Namely, the signal converter of FIG. 1 includes a light source 1 for emitting a continuous light of a constant intensity, an optical modulator 2, a driver 3 for amplifying a digital input signal to supply a signal electric power, an oscillator 4 for generating a pilot signal of a frequency f, a DC voltage source 5 for generating a DC voltage in response to feedback of an amplitude monitor signal from an output (or an amplitude monitor terminal) of the driver 3, an adder 6 for superimposing the DC voltage on the pilot signal to supply an output signal to an amplitude control terminal of the driver 3, a splitter 7 for providing a part of optical modulation signals to be output from the optical modulator 2, a monitor photodiode (monitor PD) 8 for receiving a part of the optical modulation signals, a monitor amplifier 9 for amplifying a received electric power of the monitor PD 8 to obtain a monitor signal, a mixer 10 for multiplying the monitor signal by the pilot signal, a low pass filter 11 for removing a high-frequency component (AC component) from the multiplied signal to provide a low-frequency component (DC component) as a monitor phase signal, a differential amplifier 12 for controlling a bias electric power in such that the monitor phase signal reaches a GND level, the monitor phase signal being

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input to the differential amplifier **12** wherein the other input is connected to GND, and a modulation electric power applier (bias T) **13** for superimposing the bias electric power output from the differential amplifier **12** on an AC component of the

5　signal electric power output from the driver **3** to apply an output signal to the optical modulator **2**.

As shown in **FIG. 1**, a feedback system **14** for amplitude control is constituted by a loop of the driver **3**, the DC voltage source **5**, and the adder **6**. Furthermore, a monitor circuit **15**

10　for receiving a part of optical modulation signals output to provide it as a monitor signal includes the splitter **7**, the monitor PD **8**, and the monitor amplifier **9**. Moreover, a feedback system **16** for bias control is constituted by a loop of the differential amplifier **12**, the bias T, the optical modulator

15　**2**, the monitor circuit **15**, the mixer **10**, and the low pass filter **11**.

In the signal converter shown in **FIG. 1**, a pilot signal of a frequency f is input to an amplitude control terminal of the driver **3** amplifying digital input signals, whereby

20　amplitude of a signal electric power to be supplied to the optical modulator **2** is controlled. A DC voltage of the DC voltage source **5** is controlled in such that an amplitude monitor signal of the driver **3** becomes constant in the feedback system **14**, whereby a signal electric power is controlled. However,

25　it is necessary for adjusting initially elements contained in the feedback system **14** in order to obtain the optimum amplitude

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in the optical modulator **2**.

To control automatically a bias electric power at the optimum point, a part of optical modulation signals output from the optical modulator **2** is provided by the splitter **7**, and it

5 is received by the monitor PD **8**. The received electric power is amplified by the monitor amplifier **9** to obtain a monitor signal, the monitor signal is multiplied by a pilot signal in the mixer **10**, and a monitor phase signal being a DC component is provided by the low pass filter **11**. When the monitor phase

10 signal is input to the differential amplifier **12** in which the other input is connected to GND, a bias electric power is automatically controlled in such that the monitor phase signal reaches the GND level (Japanese patent No. 2642499).

In a conventional signal converter, it is required to

15 adjust initially elements contained in the feedback system **14** in order to obtain the optimum amplitude in the optical modulator **2**. The initial adjustment is carried out by such a manner that operations for exchanging parts of the feedback system **14** or operations for adjusting finger grips of the parts

20 of the feedback system **14** are repeated while measuring optical outputs of the signal converter by means of an external measuring device. As a result, such initial adjustment decreases mass productivity of signal converter, besides it is an obstruction for reducing a cost therefor.

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SUMMARY OF THE INVENTION

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Accordingly, it is an object of the present invention to solve the above-described problems, and to provide a signal converter wherein amplitude control and bias control can be simplified.

5   In order to achieve the above-described object, a signal converter for converting a digital input signal to an optical modulation signal according to the present invention comprises a Mach-Zehnder type optical modulator to be supplied with the digital input signals controlled in amplitude, and a bias signal

10   for providing the optical modulation signal, a pilot signal-superimposing circuit for superimposing a pilot signal of a frequency on a bias control signal, a monitor circuit for providing a monitor signal by receiving a part of the optical modulation signal supplied from the optical modulator, a first

15   feedback system for providing an amplitude control signal to control an amplitude of the digital input signal in accordance with a frequency deviation signal obtained from the monitor signal, and a second feedback system for providing the bias control signal to control the bias signal in accordance with

20   a multiplying frequency deviation signal obtained from the monitor signal.

In the signal converter according to the invention, the first feedback system comprises a first mixer for multiplying the pilot signal and the monitor signal, a first low pass filter

25   for providing the frequency deviation signal based on a low frequency component obtained from an output of the first mixer,

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and a first differential amplifier for providing the amplitude control signal in accordance with a difference between an output of the first low pass filter and a first reference signal.

In the signal converter according to the invention, the second feedback system comprises a first oscillator for generating a multiplying frequency corresponding to a multiplication of the frequency of the pilot signal, a second mixer for multiplying an output of the first oscillator and the monitor signal, a second low pass filter for providing the multiplying frequency deviation signal based on a low frequency component obtained from an output of the second mixer, and a second differential amplifier for providing the bias control signal in accordance with a difference between an output of the second low pass filter and a second reference signal.

In the signal converter according to the invention, the second feedback system comprises a second oscillator for generating the frequency of the pilot signal, a band pass filter for providing a harmonic wave contained in the pilot signal, a third mixer for multiplying the harmonic wave and the monitor signal, a third low pass filter for providing a multiplying frequency deviation signal based on a low frequency component obtained from an output of the third mixer, and a third differential amplifier for providing the bias control signal in accordance with a difference between an output of the third low pass filter and a third reference signal.

In the signal converter according to the invention, the

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first oscillator generates a twofold frequency of the frequency of the pilot signal.

BRIEF DESCRIPTION OF THE DRAWINGS

5   The present invention will be explained in more detail in conjunction with appended drawings, wherein:

FIG. 1 is a circuit diagram showing a conventional signal converter;

FIG. 2 is a circuit diagram showing a signal converter

10   according to an embodiment of the present invention;

FIGS. 3A through **3D** are graphical representations showing signal waveforms in respective sections (A) through (E) in the signal converter shown in **FIG. 2**;

FIGS. 4A through **4D** are graphical representations showing

15   signal waveforms in respective sections (A) through (E) in the signal converter shown in **FIG. 2**;

FIGS. 5A through **5D** are graphical representations showing signal waveforms in respective sections (A) through (E) in the signal converter shown in **FIG. 2**;

20   **FIGS. 6A** through **6D** are graphical representations showing signal waveforms in respective sections (A) through (E) in the signal converter shown in **FIG. 2**;

FIGS. 7A through **7D** are graphical representations showing signal waveforms in respective sections (A) through (E) in the

25   signal converter shown in **FIG. 2**;

FIG. 8 is a circuit diagram showing a signal converter

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according to another embodiment of the present invention;

FIG. 9 is a circuit diagram showing a signal converter according to a further embodiment of the present invention; and

FIG. 10 is a circuit diagram showing a signal converter according to a still further embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A preferred embodiment of the present invention will be described in detail hereinafter by referring to the accompanying drawings.

As shown in FIG. 2, a signal converter according to the present invention comprises a light source 1 for emitting continuous light having constant intensity, a Mach-Zehnder type optical modulator 2, a driver 3 for amplifying digital input signals to supply a signal power, an oscillator 4 for generating a pilot signal having a frequency f, a splitter 7 for providing a part of optical modulation signal output from the Mach-Zehnder type optical modulator 2, a monitor photodiode (monitor PD) 8 for receiving a part of the optical modulation signal, a monitor amplifier 9 for amplifying an electric power received by the monitor PD 8 to obtain a monitor signal, a mixer 17 for multiplying the monitor signal by the pilot signal, a low pass filter 18 for removing a high-frequency component (AC component) from the multiplied signal to provide a low-frequency component (DC component) as a deviation signal

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as to the frequency f (hereinafter referred to as "deviation signal"), a differential amplifier **19** for controlling an output to an amplitude control terminal of the driver **3** in such that the f deviation signal reaches a GND level, the f deviation

5   signal being applied to the differential amplifier **19** as either of inputs wherein the other input is connected to GND, an oscillator **20** for generating a signal for interior reference of a twofold frequency 2f, a mixer **21** for multiplying the monitor signal by the interior reference signal, a low pass filter **22**

10   for removing a high-frequency component (AC component) from the multiplied signal to provide a low-frequency component (DC component) as a secondary monitor phase signal, a differential amplifier **23** for controlling a bias electric power in such that the 2f deviation signal reaches a GND level, the 2f deviation

15   signal being input to the differential amplifier **23** as either of inputs wherein the other input is connected to GND, an adder **24** for adding a pilot signal of frequency f from the oscillator **4** to an output of the differential amplifier **23**, and a modulation electric power applier (bias T) **13** for superimposing a bias

20   electric power containing the pilot signal on an AC component of a signal electric power output from the driver **3**.

As shown in **FIG. 2**, the signal converter of the invention includes a pilot signal superimposition circuit **25** for superimposing a pilot signal of a frequency f on a bias electric

25   power. A monitor circuit **15** for receiving a part of an optical modulation signal output to provide the signal as a monitor

signal includes the splitter **7**, the monitor PD **8**, and the monitor

amplifier **9**. Moreover, a first feedback system **26** for

providing a frequency f-component from a monitor signal to feed

back it for controlling an amplitude of a digital input signal

5   includes a loop including the differential amplifier **23**, the

driver **3**, a bias T **13**, the optical modulator **2**, the monitor

circuit **15**, the mixer **17**, and the low pass filter **18**.

Furthermore, a second feedback system **27** for providing a twofold

frequency 2f-component from a monitor signal to feed back it

10   to a bias electric power includes a loop including the

differential amplifier **23**, the pilot signal superimposition

circuit **25**, the bias T **13**, the Mach-Zehnder type optical

modulator **2**, the monitor circuit **15**, the mixer **21**, and the low

pass filter **22**.

15   In the signal converter shown in **FIG. 2** according to the

present invention, a bias point (an intermediate point in

between the upper and the lower peaks in digital signals) of

an optical modulation signal output from the Mach-Zehnder type

optical modulator **2** is varied by supplying a pilot signal of

20   frequency f which is allowed to contain in a bias electric power

to the optical modulator **2**. A part of the optical modulation

signal is divided by the splitter **7** to be received by the monitor

PD **8**. A monitor signal obtained by amplifying the received

electric power in the monitor amplifier **9** is multiplied by the

25   pilot signal of frequency f in the mixer **17**, and an f deviation

signal being a DC component is provided by means of the low pass

filter **18**. When the f deviation signal is input to the
differential amplifier **19** wherein the other input is connected
to GND, output amplitude, i.e. a signal electric power is
controlled automatically in such that the f deviation signal
reaches GND level.

On one hand, a monitor signal is multiplied by an interior
reference signal of twofold frequency 2f in the mixer **21**, and
a **2**f deviation signal being a DC component is provided by the
low pass filter **22**. When the 2f deviation signal is input to
the differential amplifier **23** wherein the other input is
connected to GND, a bias electric power (without containing a
pilot signal) is controlled automatically in such that the 2f
deviation signal reaches GND level, whereby its bias point
becomes the optimum point.

FIGS. 3A to 3D, 4A to 4D, 5A to 5D, 6A to 6D, and 7A to
7D are graphical representations showing input-output
characteristic waveforms representing relationships between
input voltages and output powers in the optical modulator **2**
being an LN modulator (MZ modulator), respectively, together
with signal waveforms in respective sections (A) through (E)
in the signal converter shown in **FIG**. 2 wherein each section
(A) shows a waveform at an input end of modulation electric power
of the optical modulator **2**, each section (B) shows an optical
waveform at which a part of an optical modulation signal is
provided, each section (C) shows a waveform of a received
electric power in the monitor PD **8**, each section (D) shows a

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waveform of 2f deviation signal to be input to the differential amplifier **23**, and each section (E) shows a waveform of f deviation signal to be input to the differential amplifier **19**. In the respective waveforms of the above figures, each abscissa

5   indicates time, and each ordinate indicates voltage or light intensity.

FIG. 3A shows a case where output amplitude of the driver **3** is the optimum amplitude V_π and a bias point is in the optimum point. As shown in a representation (A) of **FIG**. 3A, a modulation

10   electric power has the same phase with respect to a waveform enveloping the upper peak in digital signal and a waveform enveloping the lower peak in digital signal to each other. This is because a bias electric power containing a pilot signal is superimposed on an AC component of a signal electric power from

15   the driver **3**. As shown in a representation (B) of **FIG**. 3A, optical modulation signals appear with a substantially reverse phase with respect to a waveform enveloping the upper peak in digital signal (cycle 1/2f) and a waveform enveloping the lower peak in digital signal (cycle 1/2f). Since response of the

20   monitor PD **8** is slow, a digital signal component being high frequency is substantially cut off, so that a signal being an average waveform of the representation (B) in **FIG**. 3A is output. In this case, the upper peak and the lower peak vary inversely at substantially the same time in such that when the upper peak

25   is high, the lower peak becomes low in the representation (B) of **FIG**. 3A. As a result, a waveform of a received electric power

of the monitor PD **8** is substantially direct current as shown in **FIG.** 3B. Thus, a 2f deviation signal multiplied by an interior reference signal of a twofold frequency 2f in the mixer **21**, and then a high-frequency component of which is cut off with

5   the low pass filter **22** becomes zero-potential direct current as shown in **FIG.** 3C. Furthermore, an f deviation signal multiplied by a pilot signal of frequency f in the mixer **17**, and then a high-frequency component of which is cut off with the low pass filter **18** becomes zero-potential direct current

10   as shown in **FIG.** 3D.

The reason why a waveform shown in the representation (B) of **FIG.** 3A changes with 1/2f cycle is in that output amplitude of the driver **3** is the optimum amplitude V_π, and a bias point is the optimum point. More specifically, voltage changes of

15   a digital input signal from the modulation electric power applier **13** shown in the representation (A) of **FIG.** 3A become horizontal changes on its input voltage axis at an inflection point in the input-output characteristic waveform of the optical modulator **2**. Hence, output changes of the optical

20   modulator **2** are twice larger changes of a pilot signal.

FIG. 4A shows a case where output amplitude of the driver **3** is less than the optimum amplitude V_π, and a bias point is in the optimum point. As shown in a representation (B) of **FIG.** 4A, optical modulation signals appear with substantially the

25   same phase to each other with respect to a waveform enveloping the upper peak in digital signal (cycle 1/f) and a waveform

enveloping the lower peak in digital signal (cycle 1/f). More specifically, the upper and the lower peaks change almost simultaneously with each other as to time and changes in decrease and increase in the same directions in such that when the upper peak is high, the lower peak is also high. Accordingly, a waveform of received electric power of the monitor PD **8** changes with a frequency f as shown in **FIG. 4**B. A waveform of **FIG. 4**C is zero-potential direct current, while a waveform of **FIG. 4**D is higher direct current than zero-potential.

The reason why the waveform shown in **FIG. 4**C is zero-potential direct current is due to the following mechanism. An output of **FIG. 4**B is multiplied by an interior reference signal of twofold frequency 2f in the mixer **21**, so that an output of the mixer **21** is represented by the following formula:

$$\sin (2\pi ft) \cdot \sin (2\pi 2ft)$$

$$= \{-\cos (6\pi ft) + \cos (2\pi ft)\}/2$$

This output belongs to high frequency, so that it is cut off by the low pass filter **22** to be zero-potential direct current.

The reason why the waveform of **FIG. 4**D is higher direct current than zero-potential is due to the following mechanism.

Since the output shown in **FIG. 4**B is multiplied by a pilot signal of frequency f in the mixer **17**, the output of the mixer **17** is represented by the following formula:

$$\sin (2\pi ft) \cdot \sin (2\pi 2ft)$$

$$= \{-\cos (4\pi ft) + \cos (0)\}/2$$

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When a high-frequency component of the output is cut off,

only the right-hand side cos (0)/2 component remains.

FIG. 5A shows a case where output amplitude of the driver

3 is higher than the optimum amplitude V_π, and a bias point

5   is in the optimum point. As shown in a representation (B) of

FIG. 5A, optical modulation signals appear with almost the same

phase to each other with respect to a waveform enveloping the

upper peak (cycle 1/f) in digital signal and a waveform

enveloping the lower peak (cycle 1/f) in digital signal. More

10   specifically, the upper and the lower peaks change almost

simultaneously to each other in respect of time in the same

directions in such that when the upper peak is high, the lower

peak is also high. Accordingly, a waveform of received

electric power of the monitor PD **8** changes with a frequency f

15   as shown in **FIG. 5**B. However, the waveform of **FIG. 5**B is a

reversed phase with respect to that of **FIG. 4**B. In this case,

the waveform of **FIG. 5**C is zero-potential direct current, while

the waveform of **FIG. 5**D is smaller direct current than

zero-potential.

20   **FIG. 6**A shows a case where output amplitude of the driver

3 is the optimum amplitude V_π, and a bias point is lower than

the optimum point. As shown in a representation (B) of **FIG.**

6A, there is a condition wherein signals of frequencies f and

2f ride on optical modulation signal. Concerning the frequency

25   f, a waveform enveloping the upper peak is in substantially

reverse phase with respect to a waveform enveloping the lower

peak. Under the circumstances, when optical modulation

signals are averaged, signal of frequency f disappears. Namely,

a waveform of a received electric power in the monitor PD **8** has

a frequency 2f as shown in **FIG. 6**B. Accordingly, the waveform

5   of **FIG. 6**C is larger direct current than zero-potential, while

the waveform of **FIG. 6**D is zero-potential direct current.

The reason why a component of frequency 2f appears on the

waveform of **FIG. 6**B is in that modulation is effected by a

nonlinear portions, i.e. peak and trough portions of

10   input-output characteristic waveforms in the optical modulator

2, so that higher-order frequency components are superimposed

on one another.

FIG. 7A shows a case where output amplitude of the driver

3 is the optimum amplitude V_π, and a bias point is higher than

15   the optimum point. As shown in a representation (B) of **FIG.

7**A, there is a condition wherein signals of frequencies f and

2f ride on optical modulation signal. Concerning the frequency

f, a waveform enveloping the upper peak is in substantially

reverse phase with respect to a waveform enveloping the lower

20   peak. Under the circumstances, when optical modulation

signals are averaged, signal of frequency f disappears. Namely,

a waveform of a received electric power in the monitor PD **8** is

a frequency 2f as shown in **FIG. 7**B. However, the waveform of

FIG. 7B is a reversed phase with respect to that of **FIG. 6**B.

25   Accordingly, the waveform of **FIG. 7**C is smaller direct current

than zero-potential, while the waveform of **FIG. 7**D is

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zero-potential direct current.

In any of **FIG**S. **4**C to **7**C and **FIG**S. **4**D to **7**D, inclusive, the waveforms are allowed to be close to zero-potential as much as possible by means of feedback, respectively. Accordingly,

5   it is difficult to observe actually these waveforms, but these situations are emphasized for explaining a principle of operation in the circuits. As a result of the feedback, deviations are automatically adjusted in either the case where output amplitude of the driver **3** is deviated from the optimum

10 amplitude V_π, or the case where a bias point is deviated from the optimum point, so that the output amplitude of the driver **3** becomes the optimum V_π, while the bias point becomes the optimum point as shown in **FIG**. **3**A.

In the following, other embodiments of the present

15 invention will be described.

A signal converter shown in **FIG**. **8** is the one wherein only a part surrounded by a dotted frame **28** is modified with respect to the signal converter shown in **FIG**. **2**. Explanation will be made only the interior of the dotted frame **28** which contains

20 an oscillator **4** for generating principally signals each having a frequency f, a low pass filter **29** for providing signals of the frequency f from an output of the oscillator **4**, and a band pass filter **30** for providing second harmonics of signals each having a frequency 2f from an output of the oscillator **4**. The

25 output from the oscillator **4** contains somewhat harmonics other than signals of the frequency f. Thus, only the signals having

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a frequency f-component are provided by the low pass filter 29

to apply to the adder 24 as a pilot signal, and at the same time

to apply the signals to the mixer 17 as a reference signal for

converting the frequency f-component in monitor signals to DC

5   voltage. On one hand, interior reference signals of a twofold

frequency 2f is provided by the band pass filter 30 to apply

the mixer 21 as a reference signal for converting the frequency

2f-component in the monitor signals to DC voltage.

A signal converter shown in **FIG. 9** is the one wherein only

10   a part surrounded by a dotted frame 31 is modified with respect

to the signal converter shown in **FIG. 2**. In the present

embodiment, an output of the oscillator 4 is divided into four

parts, one of which is applied to the adder 24 as a pilot signal,

another is applied to the mixer 17 as a reference signal for

15   converting a frequency f-component in monitor signals to DC

voltage, and the remaining two parts are applied to a mixer 32

and a mixer 33 in the dotted frame 31 as two reference signals

each for converting frequency 2f-component in monitor signals

to DC voltage. The monitor signals are input to the mixer 32,

20   the frequency 2f-component of the monitor signals is converted

by the mixer 32 to signals of frequency f, the signals converted

are extracted by the band pass filter 34 of frequency f, and

the extracted signals are amplified by the amplifier 35. The

signals thus amplified are converted to DC voltage by the mixer

25   33, and it is extracted by the low pass filter 36.

A signal converter shown in **FIG. 10** is the one wherein

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only a part surrounded by a dotted frame **37** is modified with respect to the signal converter shown in **FIG. 2**. In the present embodiment, an output of the oscillator **4** is divided into three parts, one of which is applied to the adder **24** as a pilot signal,

5   another is applied to a mixer **38** as both reference signals served for converting a frequency f-component in monitor signals to DC voltage and for converting a frequency 2f-component in the monitor signals to signals of the frequency f-component. An output of the mixer **38** is divided into two parts, one of the

10   output from the mixer **38** is input to a low pass filter **39** for providing DC voltage, and the other is input to a band pass filter **40** for providing the frequency f-component. The DC voltage provided from the low pass filter **39** is input to the differential amplifier **19** as in the case of **FIG. 2**.

15   The frequency f-component provided by the band pass filter **40** is amplified by the amplifier **41**, and then the frequency f-component thus amplified is applied to a mixer together with one residual output of the above-described three divided outputs in the oscillator **4**. The operations in the low pass

20   filter **22** on and after are the same with those of **FIG. 2**.

      According to the signal converter of the present invention, such an advantage that amplitude control and bias control can be simplified in the signal converter is obtained.

      It will be appreciated by those of ordinary skill in the

25   art that the present invention can be embodied in other specific forms without departing from the spirit or essential

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characteristics thereof.

The presently disclosed embodiments are therefore considered in all respects to be illustrative and not restrictive. The scope of the invention is indicated by the appended claims rather than the foregoing description, and all changes that come within the meaning and range of equivalents thereof are intended to be embraced therein.